Automotive Composites Consortium (a Partnership of DaimlerChrysler [formerly Chrysler], Ford and General Motors)

Developing Structural Composites for Large Automotive Parts

In 1994, U.S. auto manufacturers believed that structural composites were the key to the future production of lightweight, fuel-efficient vehicles. Structural composites, which are blends of a polymer with glass fibers added for strength and stiffness, would result in a vehicle that weighed less and was more corrosion-resistant to one made with steel parts. In addition, one complex composite part could replace many steel subcomponent parts, thereby reducing assembly cost. U.S. manufacturers Chrysler, General Motors (GM), and Ford were collaborating as the Automotive Composites Consortium (ACC) to develop structural (load-bearing) polymer composite technology through high-risk, cooperative, pre-competitive research programs. Existing composite parts were limited in both size and load-bearing capacity. These parts could only be produced in low volumes due to high scrap rates and long production cycle times. The ACC researchers proposed to develop a prototype pickup truck box as an example of a large, strong, and durable structural component. Their research and development would require collaboration across disciplines and massive equipment. The ACC applied to the Advanced Technology Program (ATP) for a two-year project as part of the 1994 focused program, "Manufacturing Composite Structures." ATP awarded the funding in 1994 and the project began in 1995.

During this successful project, the ACC, along with suppliers, developed the processes, tools, and data necessary to produce innovative structural composite materials. The project to develop the truck box led to the establishment of the National Composite Center (NCC) in 1996, which was funded in part by the State of Ohio. After ATP funding ended in early 1997, the ACC continued developing the prototype truck box for three more years with support from the Department of Energy, NCC, and the three auto manufacturers. Extensive testing proved the pickup truck box's ruggedness and durability. Since 2001, GM and DaimlerChrysler (Chrysler merged with Daimler-Benz to become DaimlerChrysler in1998) have commercialized several components using this technology, with more expected in the future. Ford has continued development, but has not yet commercialized products in the U.S. market. Benefits of this technology have extended beyond the auto industry. For example, the rugged composite material is being used for airplane parts, marine parts, and firefighter helmets.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

* * * *

Research and data for Status Report 94-02-0027 were collected during May – June 2004.

Composite Component Production Was Evolving

Composites are created by combining two or more materials to produce a new material that has improved properties. For example, the combination of a polymeric resin and glass fibers results in a material with increased stiffness and strength. A wide range of automotive parts, such as soft seating materials and hard structural components, are made from polyurethane composites. Polyurethanes are formed when isocyanates (highly reactive derivatives of organic acids) are combined with polyols (alcohol-based chemicals). One process used to manufacture parts made of polyurethanes is called reaction injection molding (RIM). During the RIM process, the combined material is quickly injected into a complex-shaped mold under heat and pressure. Varying the speed, pressure, and temperature produces components with different mechanical properties.

As early as the 1970s, the automotive industry used RIM to produce dashboards and body panel components that had a pleasing appearance and good paint-adhesion properties. By the 1980s, manufacturers were looking for ways to gain fuel efficiency by reducing vehicle weight while maintaining structural integrity. Typically, a 10-percent weight reduction results in an improvement in fuel economy of about three to seven percent. In order to produce load-bearing components, the next step was to incorporate RIM technology with a glass fiber mat or "preform" to produce a strong polyurethane-glass fiber reinforced composite. This process was called structural reaction injection molding (SRIM). In the 1980s and early 1990s, the polyurethane reaction was too fast to mold large parts. Manufacturers had produced some medium-sized simple parts (for example, a bumper beam support, floor pans, and seat backs), but these parts were not attractive, so they had to be used in applications that were not directly visible to the consumer.

By 1994, manufacturers wanted to make larger, attractive, and strong SRIM polyurethane composite components. However, major advances in molding technology and in glass fiber preform technology would be required in order to make parts that were durable enough to replace steel. The new SRIM parts would need to include glass fibers as reinforcement (the primary load carriers) and a matrix of the reacted polyurethane. The polyurethane surface would be visible to the consumer and needed a finished look.

Auto Manufacturers Propose a Prototype Pickup Truck Box

Chrysler, Ford, and General Motors (GM) were collaborating as the Automotive Composites Consortium (ACC) to develop structural polymer composite technology for automotive applications through high-risk, cooperative, precompetitive research programs. The consortium approached ATP in 1994 for funding under a focused program, "Manufacturing Composite Structures." They proposed a project to develop a manufacturing process that would include analyzing, designing, testing, and demonstrating high-volume, low-cost methods to manufacture a composite pickup truck box and tailgate assembly. This strong, durable, lightweight truck box would be the first of potentially many structural automotive body components. Composites resist dents, scratches, corrosion, and rust, which are typical problems in steel vehicles. Moreover, composite structures weigh less.

However, this precompetitive technology was unproven and entailed significant risk, because of the many design aspects that had to work together, such as fiber placement, preform molding, RIM processes, and the chemistries of polyurethane combinations. Scrap rates of 30 percent and long production mold cycle times of 20 to 40 minutes of typical liquid molding processes had to be reduced. If successful, this project would, for the first time, facilitate high-volume production of large, complex composite parts.

ATP approved the proposal and development started in 1995. The project relied on more than 20 subcontractors to provide materials, equipment, and testing. If successful, this newly established supplier base and infrastructure would ensure the rapid commercialization of many strong, durable, lightweight components after the end of the project. The new technology would help manufacturers and suppliers produce lightweight, fuel-efficient, cost-competitive automotive products, which would help to advance the U.S. auto industry's global competitiveness. Manufacturing techniques developed during this project could also be applied to a broad range of additional products for aerospace, furniture, medical, and recreational applications.

Researchers Develop Glass Fiber and Polyurethane Processes

Consortium researchers began with computer-aided design (CAD) techniques and finite element analysis (FEA) to develop a virtual prototype truck box (see Figure 1). Software parameters needed to account for detailed part geometry, the properties of a glass fiber framework for the pickup truck box, and a polyurethane matrix to hold the fibers together and to make an attractive surface.

Figure 1. Computer-aided design of the truck box and tailgate. Ribs add strength and stiffness.

The ACC researchers had four primary objectives:

- Use glass-fiber preforming technology developed in a parallel ACC project. The researchers would combine the glass fibers and a binder (glue) on a screen to make the preform, which they would heat to 300°F to 400°F. They would move the preform to the mold where pressure formed it to its final shape.

- Develop processing technology to inject the polyurethane into the mold containing the preform and to adjust cure times, speeds, pressure, glass fiber contents, and temperatures.

- Develop joining technology using structural adhesives to integrate the composite part with the metal body of the truck.

- Develop technology for high-volume, low-cost production, which required experimenting with polyurethane chemical combinations and proportions.

Major advances in molding technology and in glass fiber preform technology would be required in order to make parts that were durable enough to replace steel.

Researchers required specific attributes of preforms:

- Conformability. The pickup truck box mold had a complex shape, and the glass fiber perform had to properly fit this shape. For example, the bottom surface was corrugated to add stiffness and strength.

- Loft (thickness). Researchers needed the preform to be compact, but to fully fill the space between the mold surfaces.

- Uniformity. Researchers needed the fibers to be oriented in many directions to achieve uniform strength and stiffness to meet performance requirements and to have the same fiber content throughout the part for good resin flow.

- Net Size. Researchers needed a perform that fit against the edge of the mold to avoid the need for in-mold or post-mold trimming, and to prevent resin from "racing" along the edge of the mold.

- Cycle time. Researchers required an adequate supply of performs to match the proposed part production rate of 15 parts per hour.

Researchers Develop SRIM Technology

The ACC preforming operation provided high-quality, net-shape glass fiber preforms that needed no preparatory work prior to molding (see Figure 2 below). The use of high quality preforms is important to achieve a rapid SRIM molding process with a low scrap rate.

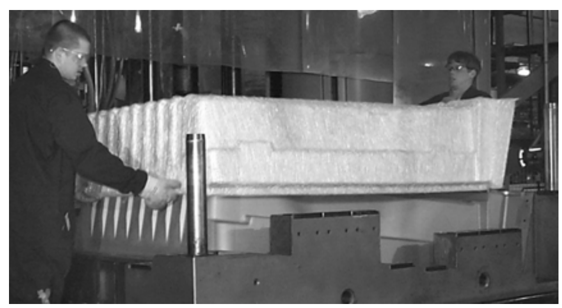

Figure 2. Loading a glass fiber preform onto the molding tool in preparation for polyurethane injection. For high-volume production the loading could be automated.

Researchers achieved the target four-minute cycle time to produce the pickup truck box and tailgate inner shell. They balanced polyurethane reaction characteristics (such as temperatures, gel time, and cure time), process conditions (including injection rates, number and location of injection ports, and press tonnage), and preform characteristics (such as fiber volume percentage and consistency).

The tailgate preform consisted of two glass-fiber preform shells wrapped around a foam core. The low-density inner foam core provided structural integrity to the molded part. Researchers were able to shape, trim, and assemble the tailgate shells in under the four-minute cycle time required. They optimized material properties to achieve weight and cost savings. They performed a study with the University of Detroit's Mercy Polymer Institute to reduce cycle times for the core, based on properties of polyurethane foam. Ultimately, they produced 50 dimensionally accurate foam cores. Future work would focus on chemical adjustments to the foam to reduce cycle time.

Three key parameters were identified for mold-filling characteristics: resin viscosity, preform permeability (allowing liquid polyurethane to pass through), and clamping force (pressure). During their work on varying pressure, the researchers discovered that too little pressure resulted in incompletely filled molds (see Figure 3 below). They proposed to use a 500-ton SRIM press, but a computer model showed it would provide too little pressure. They needed additional funding if they were to purchase a larger SRIM press. Fortunately, the State of Ohio provided significant funding to create a composite manufacturing demonstration facility in 1996 (during the ATP-funded project), called the National Center for Composite Systems Technology (later renamed the National Composite Center [NCC]). The ACC pickup truck box was the first project carried out at the NCC demonstration facility. In 1997, the NCC acquired a 1,000-ton SRIM press to use on the ACC project. However, additional development was still needed to complete the prototype pickup box. After the conclusion of the ATP-funded project in 1997, the ACC continued to work at the NCC. Researchers would eventually estimate that they needed a 2,000-ton press to consistently force the resin down the vertical walls.

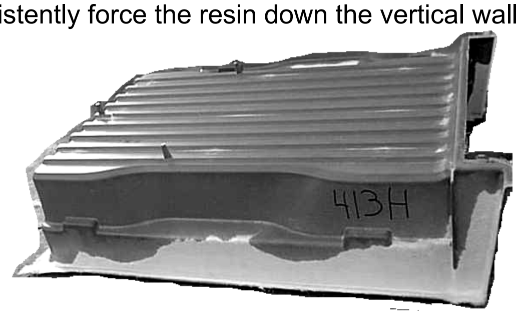

Figure 3. Example of an incompletely filled box molding, which was a result of too little pressure.

Development Advances Prototype Pickup Box

Although the prototype pickup truck box was not yet completed when the ATP-funded project ended in 1997, the ACC and its suppliers had made significant progress and anticipated eventual success. They had accomplished the following: developed a unique design for an all-composite box assembly, populated a database of ACC-measured materials' properties; identified material, design, and processing parameters; fabricated a development plaque mold and production quality molds for the box and tailgate; identified an appropriate structural adhesive; and strengthened their supplier base capability. They received one patent for ATP-funded developments and shared knowledge with the industry through publications and presentations. They had equipment in place at the NCC and had identified the next steps to validate the performance of the prototype. For example, they knew that they needed a heavier press and that they would need to develop an "injection-compression" process in which polyurethane would be injected into the mold before closing the mold completely. No models existed to simulate the injection-compression process in detail. Researchers at NIST were attempting to create and verify a software tool that could do this. Subsequent to the ATP program the ACC received $3 million in additional funds from the Department of Energy, as well as ongoing internal funding from each of the three auto manufacturers to continue the development. Moreover, they continued chopped-fiber preforming and SRIM molding development work at the NCC.

SRIM Composites Compare with Steel

SRIM composites have both advantages and disadvantages when compared to steel. Automating the SRIM processes decreased the initial cost of developing new complex-shaped, consolidated structural composite parts. Composites resist dents, scratches, corrosion, and rust, problems that have traditionally plagued pickup truck owners. Comparable steel parts would have to be assembled from multiple subcomponents that are welded together (and steel subcomponents require expensive stamping dies). Moreover, automated SRIM processes have a cost advantage for small production runs of composite parts for specialized vehicles. This is beneficial when auto manufacturers need to produce more variety and specialization in models in order to meet consumer demand. Composites also weigh less. However, the lower cost of steel still provides an advantage in large production volumes. Furthermore, consumers have traditionally believed that steel is strong, while plastic is "cheap." Manufacturers needed to market the benefits of lightweight, tough, durable, long-lasting composites to the public in order to further its acceptance.

Manufacturers Pursue Development, Testing, and Commercialization

In 1997, the ACC, supplier companies and NCC, continued developing the SRIM technology and met the goals of the program. The ACC prototype SRIM composite box weighed less than a corresponding structure in steel (a 36-pound savings on the pickup truck box, or 33 percent), met the performance requirements of a truck box, and had inherently better durability characteristics than steel. The ACC demonstrated the feasibility of its productivity goals and a cost model estimated comparable cost of a unique steel box produced at the target volume of 50,000 units per year.

In a proprietary program GM conducted pickup truck box testing and development in 1998 and 1999, investing more than $60 million. Engineers tested 48 pickups in some of the worst operating environments in North America: phosphate and sulfur mines, chemical environments, and tar sand fields. They drove the trucks for two years and 1.2 million miles in temperatures that ranged from -40°F to 170°F. All the boxes sustained minimal damage, which validated the composite's performance ("Composites Build a Tougher Truck," Composites Technology, April 2002, pp. 32-36). GM's SRIM composite pickup truck box won an award from *Popular Science* magazine in 1999 for the "Best of What's New." The magazine called it "a breakthrough in the use of structural composites." GM released the truck box to the public as an $850 option on the 2001 Chevrolet Silverado (see Figure 4). At the same time, GM released the SRIM composite midgate (a door that folds down to expand cargo room) on the Chevrolet Avalanche (standard on all models, 53,000 units were sold in 2001; 90,000 in 2002; and 93,000 in 2003). GM also released inner tailgate sections on the Cadillac Escalade EXT (also standard, 546 units were sold in 2001, 13,000 in 2002, and 11,000 in 2003). The Silverado pickup truck box option was discontinued in 2003.

Figure 4. The Chevrolet Silverado pickup truck box and tailgate, manufactured from SRIM composite, were released to the public as an option in 2001.

Ford has also focused on the preform technology. The company has developed marketable products, but has not yet commercialized any products in the U.S. market.

DaimlerChrysler has commercialized floor covers for its 2005 minivans that are manufactured with SRIM technology. Its "Stow 'n Go" system allows consumers to fold down the second- and third-row seats into the floor in the Chrysler Town & Country LX and the Dodge Grand Caravan SXT. DaimlerChrysler expects to sell more than 250,000 "Stow 'n Go" minivans per year, which would be the highest volume application of this technology to date.

Although manufacturers have not calculated direct fuel savings from these components, as more composite components are implemented over time, the weight savings (15 to 33 percent) may result in noticeable fuel economy increases in the range of 4 to 20 percent.

Industries Discover New Applications for SRIM

In addition to automotive applications, benefits of the ATP-funded SRIM technology have also extended to other industries. Boeing is using SRIM composites to manufacture parts for the Air Force C-17 cargo plane. Compared to previous composite parts, the SRIM tail cone cost 80 percent less and a SRIM access door cost 46 percent less and was 9 percent lighter. It is anticipated that additional SRIM aircraft parts will be manufactured in the future. Boeing is expanding SRIM composite use in its new 787 “Dreamliner” series passenger planes currently under development (see Figure 5 below). This is the first airliner with the majority of its large assemblies made of composite materials, including its 22-foot-wide fuselage and its super-efficient wings. Using SRIM composite parts results in a 3-percent improvement in fuel efficiency and an overall 20-percent fuel savings compared with the 747 model. The Dreamliner can carry up to 289 passengers, and its first commercial flight is anticipated in 2008.

Figure 5. Boeing’s 787 “Dreamliner” uses SRIM composites for structural parts, increasing fuel efficiency by 3 percent. Overall fuel savings is 20 percent compared with the 747. Its first commercial flight is anticipated in 2008.

SRIM composites have also been used in firefighter helmets manufactured by Lion Apparel. In addition to eliminating two steps in the manufacturing process, production efficiency was increased by 35 percent, the raw material inventory reduced, and labor costs reduced. The scrap rate was reduced from 20 percent to less than 3 percent. The resulting helmets were 15-percent lighter than previous composite helmets and had 15-percent greater impact resistance.

The prototype composite box weighed less than a corresponding structure in steel, met the performance requirements of a truck box, and had inherently better durability characteristics than steel.

SRIM composites have also contributed to benefits in the marine industry. SeaRay, a division of Brunswick Corp., uses SRIM technology to produce boat motor covers in response to upcoming U.S. Environmental Protection Agency emissions standards for the manufacturing process. By 2007, manufacturers must use closed molding processes to minimize volatile organic compound emissions. This technology replaces existing spraying in an open atmosphere.

The ACC and NCC continue to enhance SRIM technology by building on the ATP-funded developments. As of 2004, for example, they are examining the use of carbon fiber in place of glass fiber for a heavily stressed support piece used between the front and rear doors on a four-door sedan. Carbon fiber is stiffer and stronger than fiberglass and provides a weight savings of 50 to 60 percent over steel.

Conclusion

Chrysler (now DaimlerChrysler), Ford, and General Motors (GM) jointly formed the Automotive Composites Consortium (ACC) in 1988 to develop innovative polymer composite technology. They wanted to use this technology to reduce the weight and corrosion in automobile and truck parts compared with existing steel structural parts, because reduced weight would improve fuel economy. The ACC aimed to make composites more affordable. The group applied to ATP under a focused program, “Manufacturing Composite Structures” in 1994 for a two-year project to develop a prototype pickup truck box using a process called structural reaction injection molding (SRIM) as an example of a lightweight and tough structural component. This project began in 1995 and helped to establish the National Composite Center (NCC) in 1996 in Ohio, which focuses on developing cost-competitive composite materials and processes. Researchers produced net-shape glass fiber performs; produced finished sample plaques; and met requirements for shape, thickness, strength, stiffness, and scrap. Following the conclusion of the ATP-funded project, the ACC and NCC acquired the needed equipment and successfully produced prototype pickup truck boxes in 1999. GM released the SRIM pickup truck box to the public as an option on the Chevrolet Silverado pickup truck in 2001, achieving a 33-percent weight savings over steel (however, they discontinued the option in 2003). The company simultaneously released standard parts for the Chevrolet Avalanche and Cadillac Escalade. DaimlerChrysler has also released commercial SRIM components for its 2005 minivans. Additional applications of this successful ATP-funded technology include strong, lightweight components for aircraft, firefighter helmets, and marine motor covers. Project researchers shared their developments through one granted patent and several articles and presentations. As public acceptance of tough, durable composites increases, applications are expected to broaden.

PROJECT HIGHLIGHTS
Automotive Composites Consortium (A partnership of DaimlerChrysler [formerly Chrysler], Ford and General Motors)

Project Title: Developing Structural Composites for Large Automotive Parts (Automotive Composite Structures: Development of High-Volume Manufacturing Technology)

Project: To develop a composites manufacturing process called structural reaction injection molding (SRIM) into a cost-effective means to produce large automotive structural parts, such as the box of a pickup truck.

Duration: 3/1/1995 - 2/28/1997
ATP Number: 94-02-0027

Funding (in thousands):**

ATP Final Cost	$2,575	47%
Participant Final Cost	$2,855	53%
Total	$5,430	

Accomplishments: With ATP funding, the Automotive Composites Consortium (ACC) successfully produced a prototype box for a pickup truck that is stronger and more durable than steel, does not rust, is visually attractive, requires no bed liner, and improves fuel efficiency through its light weight (36 pounds, or 33 percent, lighter than steel). This pickup truck box gave the ACC member companies (General Motors [GM], Ford, and Chrysler, which later became DaimlerChrysler) the knowledge and tools to develop commercial products and to continue innovative research, based on this initial success. In addition, the SRIM project contributed the following:

- ATP support of the project helped to establish the National Composite Center (NCC) in Ohio in 1996, which promotes, develops, and applies advanced composite technology to aerospace, defense, automotive, and commercial markets. NCC also received funding from the State of Ohio.

- ACC received $3 million follow-on research funding from the Department of Energy from 1997 to 2000 to complete the program.

- NCC conducted related research with the Air Force Research Laboratory at Wright-Patterson Air Force Base for aerospace composite preform parts, beginning in 1997. They demonstrated significant cost reductions in 1999 for the Air Force C-17 cargo aircraft. For example, a tail cone cost 80 percent less, and a fighter access door cost 46 percent less and was 9 percent lighter than previous composite parts.

- GM won a "Best of What's New" award from Popular Science magazine for the Chevrolet Silverado composite pickup truck box in 1999; the magazine lauded it as "a breakthrough in the use of structural composites."

- ACC began work in 2001 at NCC on using carbon fiber in the B-pillar (the support piece between the front and rear doors) on a four-door sedan. Carbon-fiber-based SRIM is the next generation of lightweight, strong, and durable structural composite parts; they are stiffer and stronger than steel, with a 50- to 60-percent weight savings. A 10-percent overall weight savings is expected to increase fuel efficiency by 3 to 7 percent.

The ACC received one patent for SRIM technology from this ATP-funded project:

- "Self-contained constant stress/constant strain test fixture"
  (No. 5,798,463: filed February 12, 1997; granted August 25, 1998)

Commercialization Status: The original technology has been evolving through additional research and new applications. Some examples of commercial products that rely on the lightweight, high-strength, corrosion-resistant, and flexible qualities of this SRIM technology include the following:

- Pickup truck box and tailgate assembly for the Chevrolet Silverado went into production as an option in the 2001 model year, discontinued in 2003. The commercial box weighed 50 pounds less than the conventional welded steel box (33-percent savings). The tailgate is 15 pounds lighter than steel and has a 1,000-pound load-carrying capacity (compared to 600 pounds for steel).

- Midgate (a door that folds down to extend cargo space) for the Chevrolet Avalanche, beginning in the 2001 model year. Sold 53,000 units in 2001, 90,000 in 2002, and 93,000 in 2003.

- Inner tailgate sections for the Cadillac Escalade EXT hybrid sport utility vehicle, beginning in the 2001 model year. Sold 546 units in 2001, 13,000 in 2002, and 11,000 in 2003.

** As of December 9, 1997, large single applicant firms are required to pay 60% of all ATP project costs. Prior to this date, single applicant firms, regardless of size, were required to pay indirect costs.

PROJECT HIGHLIGHTS
Automotive Composites Consortium (A partnership of DaimlerChrysler [formerly Chrysler], Ford and General Motors)

- Floor sections for the "Stow 'n Go" system to fold down second- and third-row seats in the Chrysler Town & Country LX and the Dodge Grand Caravan SXT, beginning in the 2005 model year. Sales in excess of 250,000 units are anticipated.
- High-performance aircraft components by Boeing that include a C-17 airplane tail cone and an access door.
- Structural components on Boeing's 787 "Dreamliner" series passenger planes under development. Composites save 3 percent in fuel efficiency and contribute to an overall 20-percent fuel savings. Commercial flight is anticipated in 2008.
- Fire helmet shells manufactured by Lion Apparel (15-percent lighter than previous composite helmets with 15-percent greater impact resistance).
- Boat motor covers manufactured by the SeaRay Marine Division of Brunswick Corp. The SRIM process reduces volatile organic compound emissions compared with existing processes.

Outlook: The outlook for continuing the commercial development of the SRIM technology is good. As structural composite parts prove their strength and durability and as consumer demands for fuel efficiency increase over time, analysts predict that consumers will be more accepting of composite structural parts.

Composite Performance Score: * * * *

Focused Program: Manufacturing Composite Structures, 1994

Company:
DaimlerChrysler
CIMS 429-18-04
2301 Featherstone Road
Auburn Hills, MI 48326

Contact: Dr. Douglas Denton
Phone: (248) 512-8140

Company:
General Motors Research and Development
Materials and Process Lab
Mail Code 480-106-831
30500 Mound Road
Warren, MI 48090

Contact: Stanley Iobst
Phone: (586) 986-1223

Company:
Ford Motor Company
Research and Advanced Engineering
Manufacturing and Processing Department
2101 Village Road, MD3135
Dearborn, MI 48121-2053

Contact: Jim deVries
Phone: (313) 322-3494

Subcontractor:

- Altair Engineering
  Troy, MI
- American GFM
  Chesapeake, VA
- American Sunroof Corporation
  Southgate, MI
- ATI Systems, Inc.
  Madison Heights, MI
- Bayer Chemical
  Pittsburgh, PA
- Bucciero & Associates, PC
  Troy, MI
- Chemstress Consultants, Inc.
  Akron, OH
- Collins & Aikman (formerly Textron Automotive)
  Americus, GA
- Delsen Testing Laboratories, Inc.
  Glendale, CA
- Excel Pattern Works, Inc.
  Dearborn, MI
- GenCorp Automotive Research
  Akron, OH
- Gilchrist Metal Fabricating
  Hudson, NH
- Hi-Tech Mold & Engineering, Inc.
  Grand Rapids, MI
- H.S. Die and Engineering
  Grand Rapids, MI
- Intelligent Structures, Inc
  Plymouth, MI
- Magna International
  Southfield, MI

PROJECT HIGHLIGHTS
Automotive Composites Consortium (A partnership of DaimlerChrysler [formerly Chrysler], Ford and General Motors)

- MSX International (formerly MascoTech)
  Auburn Hills, MI
- National Composite Center
  Kettering, OH
- RP/C Alliance Corp.
  Southfield, MI
- SIA (Sovereign Specialty Chemicals, now part of Henkel)
  Chicago, IL
- Structured Solutions
  Troy, MI
- Tooling Technology Center
  Windsor, Ontario, Canada
- Troy Tooling, Inc.
  Rochester Hills, MI
- Mercy Polymer Institute
  University of Detroit
  Detroit, MI
- Weber Tools & Mold
  Midland, Ontario, Canada

Publications: Researchers shared their knowledge about SRIM through the following publications:

- Lee, D. “National Composite Center Produces Pickup Truck Bodies.” *Society for the Advancement of Material and Process Engineering (SAMPE) Journal*, March/April 1999.
- Romanchik, D. “Tests Characterize Composite Materials and Bonds.” *Automotive Test Report*, May 1999.
- “USCAR Composite Technology Commercialized by GM.” Press release from U.S. Council for Automotive Research (USCAR), February 2, 2000.
- “Truck Makers Choose Different Routes for Composite Cargo Boxes.” *Composites Technology*, p. 19, March-April 2000.
- Denton, D. L., C. H. Mao, D. E. Willertz, N. G. Chavka, J. S. Dahl, E. D. Kleven, T. J. Dearlove, C. A. Di Natale, E. M. Hagerman, S. A. Iobst, J. A. Schroeder, and R. A. Bergen. "Development of a Cost-Effective SRIM Manufacturing Process for a Composite Pickup Truck Box." *Proceedings of SAMPE* (publication and conference), Midwest Conference, Dearborn, MI, p. 342, September 12-14, 2000.
- Iobst, S. A., C. H. Mao, and D. L. Denton. “Use of Real Time Data Acquisition to Optimize the SRIM Process for a Pickup Truck Box.” *Proceedings of SAMPE* (publication and conference), Midwest Advanced Materials and Processing Conference, Dearborn, MI, p. 355, September 12-14, 2000.
- “ACC Successfully Demonstrates SRIM Technology: ACC Development Leads to OEM Application F3P Fiber Preforming Used for the Aston Martin Vanquish.” *USCAR Newsletter*, Spring 2001.
- “ACC Successfully Demonstrates SRIM Technology: Process Is Cost-Effective and Efficient; Pickup Box 25 Percent Lighter than Steel.” *USCAR Newsletter*, Spring 2001.
- Brosius, D. “Composites Build a Tougher Truck.” *Composites Technology*. p. 32-36, April 2002.

Presentations: Researchers also shared knowledge through the following presentations:

- Denton, D. L., C. H. Mao, D. E. Willertz, N. G. Chavka, J. S. Dahl, E. D. Kleven, T. J. Dearlove, C. A. Di Natale, E. M. Hagerman, S. A. Iobst, J. A. Schroeder, and R. A. Bergen. "Development of a Cost-Effective SRIM Manufacturing Process for a Composite Pickup Truck Box." SAMPE Conference, Midwest Conference, Dearborn, MI, September 12-14, 2000.
- Iobst, S. A., C. H. Mao, and D. L. Denton. “Use of Real Time Data Acquisition to Optimize the SRIM Process for a Pickup Truck Box.” SAMPE Conference, Midwest Advanced Materials and Processing Conference, Dearborn, MI, September 12-14, 2000.
- Iobst, S. A., C. H. Mao, and D. L. Denton. “Optimizing the SRIM Process for the ACC Composite Pickup Truck Box Molding,” presented at the Lightweight Materials in Automotive Applications Workshop, Windsor, ON, June 4, 2001.